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(57) A direct current to be measured in a conductor 10 produces magnetisation of a core 18 which is balanced by the demagnetisation produced by a coil 16. The coil 16 is supplied with an increasing ramp current generated digitally from a clock pulse generator 24, counter 28 and D-A converter 30. The ramp is automatically terminated when a sensing coil 20 detects reversal of the magnetisation, whereupon a monostable 38 also halts a BCD counter 26 whose result is displayed 42 as a measure of the current. The starting of counter 26 is somewhat delayed by a second monostable 40 to provide an offset to compensate for the extra demagnetising current required to overcome residual magnetisation in the core 18.



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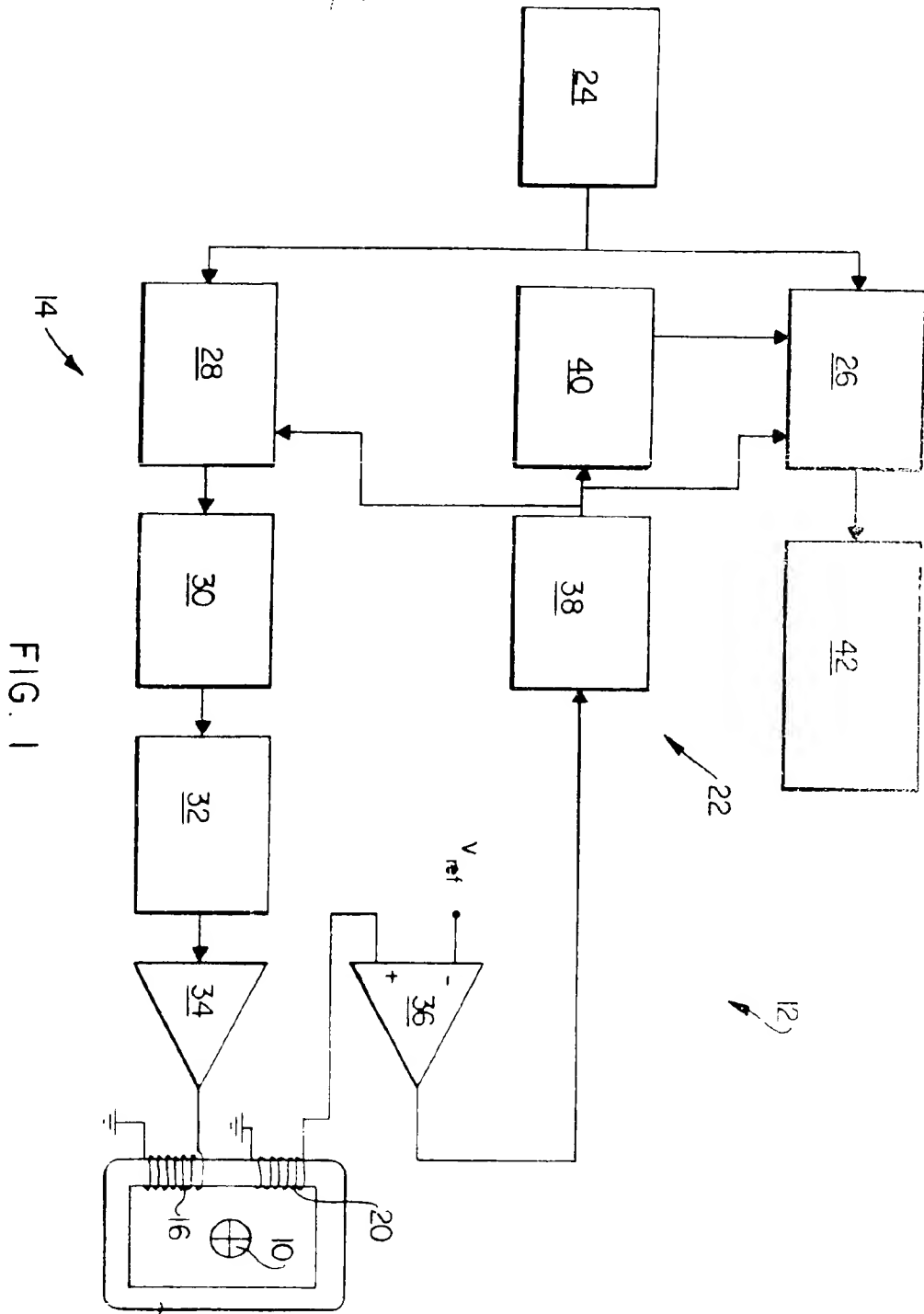


FIG. 1

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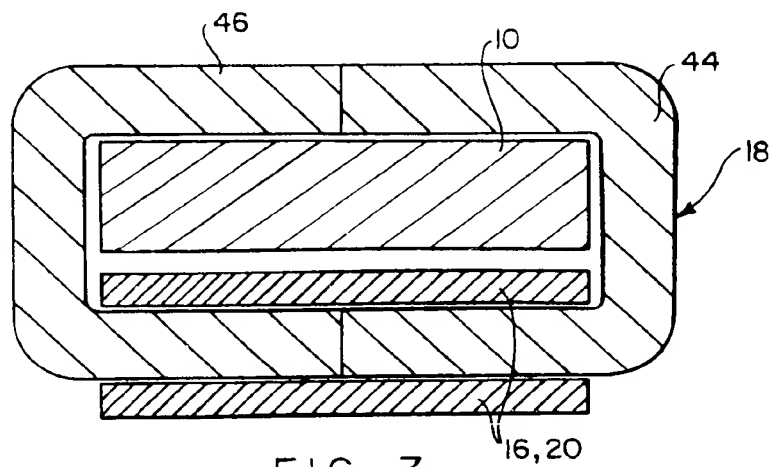


FIG. 3

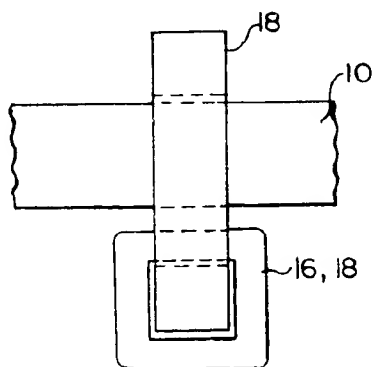


FIG. 4

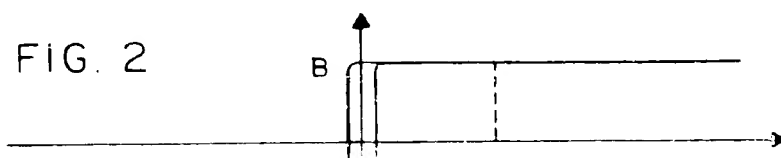


FIG. 2

## SPECIFICATION

## Current measurement

- 5 This invention relates to an apparatus for and a method of measuring the magnitude of a D.C. current.

According to the invention there is provided an apparatus for measuring the magnitude of a D.C. current, which includes

- 10 a generating means for generating a demagnetising current in a predetermined region of space in which, in use, the D.C. current establishes a magnetic field, to decrease the strength of the magnetic field to a predetermined value; and

- 15 a determining means for determining the magnitude of demagnetising current required to decrease the strength of the magnetic field to the predetermined value.

- 20 Further according to the invention there is provided a method of measuring the magnitude of a D.C. current, which includes

- generating a demagnetising current in a region of space in which the D.C. current has established a magnetic field so as to decrease the strength of the magnetic field; and

- determining the magnitude of demagnetising current required to decrease the strength of the magnetic field to a predetermined value.

- 30 The apparatus may include a constraining means for constraining the magnetic field. This may be done by means of a suitably shaped constraining member that is of a suitable magnetic material. Those skilled in the art will appreciate that the

- 35 constraining member may particularly be a toroid. The constraining member may further have a sufficiently large cross-sectional area for leakage flux to be below a predetermined value. Further, the constraining member may be of a material that has a

- 40 saturating magnetisation characteristic with a high permeability before saturation and a low permeability after saturation. Thus, the constraining member may be of mumetal, si-steel, or a ferrite. Instead of monitoring the magnetic field, the flux density in the

- 45 toroid may be monitored, and the demagnetising current required to decrease the flux density to a predetermined value determined. Further, the toroid may be of one piece of material or may, more preferably, be of two or more separate core portions which may be engaged with one another about a

- 50 conductor carrying the D.C. current to be measured. The apparatus may further include a demagnetising coil through which the demagnetising current is passed, the demagnetising coil thus being electrically connected to the demagnetising current generat-

determining the magnitude of some other parameter which is representative of the magnitude of the demagnetising current. Thus, the demagnetising current generating means may be adapted to generate a ramp current, so that the magnitude of the demagnetising current increases at a constant rate, and the determining means may then be adapted to determine the length of time required for the strength of the magnetic field to decrease to the predetermined value. Alternatively, the average value of demagnetising current, or the like may be determined.

- As indicated above, the magnitude of the D.C. current may be measured by determining the magnitude of demagnetising current required to decrease the strength of the magnetic field or its flux density to a predetermined value. This predetermined value may be as desired. It will be appreciated that the most suitable value will be zero. However, as most magnetic materials have a saturating, hysteresis characteristic the magnitude of demagnetising current required to decrease the magnitude of flux density in the toroid to zero may preferably be determined rather than the magnitude of demagnetising current required to decrease the strength of the magnetic field to zero. It will be appreciated that the former will lead to an error that is acceptably small if the toroid is heavily saturated by the D.C. current to be measured, as will usually be the case. Alternatively, as the error will be a constant value, it may be taken into account.

The invention is now described, by way of an example, with reference to the accompanying drawings, in which:

- 100 *Figure 1* shows schematically an apparatus for measuring the magnitude of a D.C. current in accordance with the invention;

*Figure 2* shows the magnetisation characteristic of a toroid forming part of the apparatus of *Figure 1*;

- 105 *Figure 3* shows a sectional view of the toroid, the conductor in which the D.C. current to be measured flows, and of coils wound on the toroid; and

*Figure 4* shows a side view of the toroid, the conductor and the coils shown in *Figure 3*.

- 110 Referring to *Figure 1*, an apparatus for measuring the magnitude of a D.C. current in a conductor 10 is designated generally by reference numeral 12. The apparatus 12 comprises electronic circuitry, designated generally by reference numeral 14 for generating a ramp current signal and supplying it to a demagnetising coil 16; a toroid 18; a sensing coil 20 for sensing the rate of change of flux density in the toroid 18; and electronic circuitry indicated generally by reference numeral 22 for determining the magnitude of demagnetising current (or a parameter

representative of the magnitude of the demagnetising current). The electronic circuitry 22 may comprise a sensing coil.

Those skilled in the art will understand that instead of a sensing coil, the electronic circuitry 22 may comprise a

fluxmeter, a fluxmeter, a lock-in amplifier, a binary coded decimal (BCD) counter 26, a binary counter 28, a digital to analogue converter 30, a low pass filter 32, a voltage to current converter 34, a

current to voltage converter 36, a current to voltage converter 38, a voltage to current converter 40, a

a display unit 42.

The clock 24 generates a series of clock pulses, at a suitable frequency, which are supplied to the BCD counter 26 and the binary counter 28. The output of the binary counter is supplied to the converter 30 which supplies a stepped voltage signal to the low pass filter. This voltage signal is smooth to provide a ramp voltage signal which is supplied to the voltage to current converter 34. This converter 34 thus provides a ramp current signal which has a steadily increasing magnitude. This current signal is supplied to the demagnetising coil 16.

Referring to Figure 2, shown therein is the magnetisation characteristic of the toroid 18. With no current in the demagnetising coil 16 and the sensing coil 20, the D.C. current that is to be measured which flows in the conductor 10 sets up a magnetic field in the toroid 18 having a strength  $H_1$  as indicated in Figure 2. When current flows in the demagnetising coil 16 the strength of the magnetic field is decreased. However, as the toroid has a low permeability in its saturated mode, the flux density remains substantially constant at its saturated value. Accordingly, the sensing coil 20 supplies a very low voltage signal to the comparator 36. It will be understood that the strength of demagnetising current required to decrease the strength of the magnetic field to zero is proportional to the magnitude of the D.C. current. Further, the magnitude of demagnetising current at which the flux density in the toroid is zero is also proportional to the magnitude of D.C. current once a constant error is taken into account, this constant error being the magnitude of current to reduce the residual flux density in the toroid when the field strength is zero, to zero. It will, however, be appreciated that if this magnitude of current is significantly small in comparison with the magnitude of current to be measured that the error resulting therefrom may be ignored.

Thus, as the demagnetising current increases a point is reached at which the flux density changes from a saturated value in one direction to a saturated value in the other direction. This rapid change of flux induces a voltage signal in the sensing coil 20 which is of sufficient magnitude to be detected by the comparator 36. The comparator 36 therefore supplies a signal to the first monostable multivibrator 38. This supplies a first timing signal to the BCD counter 26, the second multivibrator 40 and the binary counter 28. This first timing signal is supplied to a reset input of the binary counter 28 with the result that this counter 28 is held at zero for the duration of the first timing signal. The first timing signal is, on the other hand, supplied to a hold input of the BCD counter which results in the BCD counter

the clock 24 at a suitable value the number of counts counted by the BCD counter 26, or equally the time taken for the ramp to increase to the required value, will be equal to the magnitude of the DC current.

At the end of a suitable time period the second monostable multivibrator 40 supplies a reset pulse to a reset input of the BCD counter 26 which resets the count of this counter to zero. At the end of a time period which is that of the first timing signal supplied by the monostable multivibrator 38 the binary counter 28 starts counting again and the BCD counter is reset to zero for a duration given by the delay of monostable 40. The BCD counter counts therefore less pulses than it would if both binary and BCD counters are enabled at the same time. Due to the shape of the magnetization curve the impulse from the sensing coil is generated at a higher amplitude of current ramp than necessary to counter the measured current. If the time delay of monostable 40 is arranged such that the number of 'lost' counts during 'zero BCD' period equals number of counts encountered between time, at which zero strength of magnetic field is reached and time of cessation of current ramp, then the BCD counter will display counts proportional to measured current.

Referring now to Figures 3 and 4, shown therein are the conductor 10 the toroid 18 and the coils 16 and 20. Further, as shown, the toroid 18 comprises two strip wound C-cores 44 and 46 which are secured together about the conductor 10 and to the coils 16 and 20 by means of a steel strap (not shown). The coils 44 and 46 are of oriented 3% si-steel and have a suitable cross-sectional area to give negligibly small leakage flux. Further, the coils 16 and 20 are wound co-axially.

In a prototype apparatus for measuring D.C. currents ranging from 200 amps to 1 000 amps in a rectangular conductor having cross-sectional dimensions of 83 mm x 20 mm the toroid had a cross-sectional area of 156 mm<sup>2</sup> and an average length of 288 mm; the demagnetising coil 16 had 500 turns; the sensing coil 20 also had 500 turns; the voltage comparator 36 had an input impedance of 10 kilo ohm; and the converter 34 provided a current ramp having a gradient of 16 amp per second; and the clock 24 had a frequency of 8 kHz. With this apparatus the current of the counter 26 was linear with respect to the D.C. current, achieving linearity better than 0.3% in the range of 0.3-1 kiloamps declining to 3% at 250 amps, 6% at 200 amps and 15% at 150 amps.

By this means, D.C. currents of high magnitudes may be easily, accurately and precisely measured with apparatus that is relatively cheap and unsophisticated. Having now particularly described and

illustrated the invention, it will be understood that the flux density in the toroid 18 is zero, or of opposite polarity, or corresponding  $y$ , decreases in magnitude to zero. This number of counts is also representative of the D.C. current to be measured, as explained above and is also proportional to the magnitude of the current to be measured.

What I claim is:

1. An apparatus for measuring the magnitude of a D.C. current, which includes

a conductor carrying the current to be measured, a toroid wound about the conductor, a demagnetising coil wound about the toroid, a sensing coil wound about the toroid, a voltage comparator, a converter, a clock, a BCD counter, a binary counter, a first monostable multivibrator, a second monostable multivibrator, a display unit, and a reset input of the BCD counter, which is connected to the output of the second monostable multivibrator.

which, in use, the D.C. current establishes a magnetic field, to decrease the strength of the magnetic field to a predetermined value; and

5 a determining means for determining the magnitude of demagnetising current required to decrease the strength of the magnetic field to the predetermined value.

2. An apparatus as claimed in claim 1, which includes a constraining means for constraining the magnetic field.

3. An apparatus as claimed in claim 2, in which the constraining means is a suitably shaped constraining member that is of a suitable magnetic material, and the determining means is adapted to determine the magnitude of demagnetising current required to decrease the magnitude of flux density in the constraining member to a predetermined value.

4. An apparatus as claimed in claim 3, in which the constraining member is a toroid.

5. An apparatus as claimed in claim 4, in which the constraining member has a sufficiently large cross-sectional area for leakage flux to be below a predetermined value.

6. An apparatus as claimed in claim 3, in which the constraining member is of a material that has a saturating magnetisation characteristic and has a high permeability before saturation and a low permeability after saturation.

7. An apparatus as claimed in claim 6, in which the constraining member is of mumetal, si-steel or a ferrite.

8. An apparatus as claimed in claim 4, in which the toroid is formed from two or more separate core portions.

9. An apparatus as claimed in any one of the preceding claims which includes a demagnetising coil electrically connected to the demagnetising current generating means.

10. An apparatus as claimed in claim 3, in which the determining means includes a voltage generating means for generating a voltage signal, the magnitude of which is determined by the rate of change of flux density in the constraining member.

11. An apparatus as claimed in claim 10, in which the voltage generating means comprises a sensing coil.

12. An apparatus as claimed in any one of the preceding claims, in which the determining means is adapted to determine the magnitude of the demagnetising current indirectly by determining the magnitude of some other parameter which is representative of the magnitude of the demagnetising current.

13. An apparatus as claimed in claim 12, in which the demagnetising current generating means is

the determining means is adapted to determine the magnitude of demagnetising current required to decrease the magnitude of flux density in the constraining member to substantially zero.

16. An apparatus for measuring the magnitude of a D.C. current, substantially as described in the specification with reference to the accompanying drawings.

17. A method of measuring the magnitude of a D.C. current, which includes generating a demagnetising current in a region of space in which the D.C. current has established a magnetic field so as to decrease the strength of the magnetic field; and

18. determining the magnitude of demagnetising current required to decrease the strength of the magnetic field to a predetermined value.

18. A method as claimed in claim 17, in which the strength of the magnetic field is decreased to substantially zero.

19. A method as claimed in claim 17 or 18, in which the magnetic field is substantially constrained to a toroidal region of space.

20. A method as claimed in any one of claims 17 to 19, in which the magnetic field is located in a ferromagnetic material having a saturating magnetisation characteristic and having a high permeability before saturation and a low permeability after saturation.

21. A method as claimed in any one of claims 17 to 20, which includes providing a toroidal member about a conductor in which the D.C. current flows.

22. A method as claimed in any one of claims 17 to 21, in which the magnitude of demagnetising current is determined indirectly by determining the magnitude of some other parameter which is representative of the magnitude of the demagnetising current.

23. A method as claimed in claim 22, in which a demagnetising current with a constant rate of increase is generated and the time taken for the strength of the magnetic field to be decreased to the predetermined value is determined.

24. A method as claimed in claim 20, which includes monitoring the magnitude of flux density in the material.

25. A method as claimed in claim 24, in which the magnitude of the flux density is monitored by monitoring its rate of change.

26. A method as claimed in claim 25, in which the rate of change of magnitude of the flux density is monitored by generating a voltage signal having a magnitude in accordance therewith.

27. A method of measuring the magnitude of a

14. An apparatus as claimed in any one of the preceding claims, in which the determining means is adapted to determine the magnitude of demagnetising current required to decrease the strength of the magnetic field to a predetermined value.